



Energy, Mines and
Resources Canada

Énergie, Mines et
Ressources Canada

CANMET

Canada Centre for
Mineral and Energy
Technology

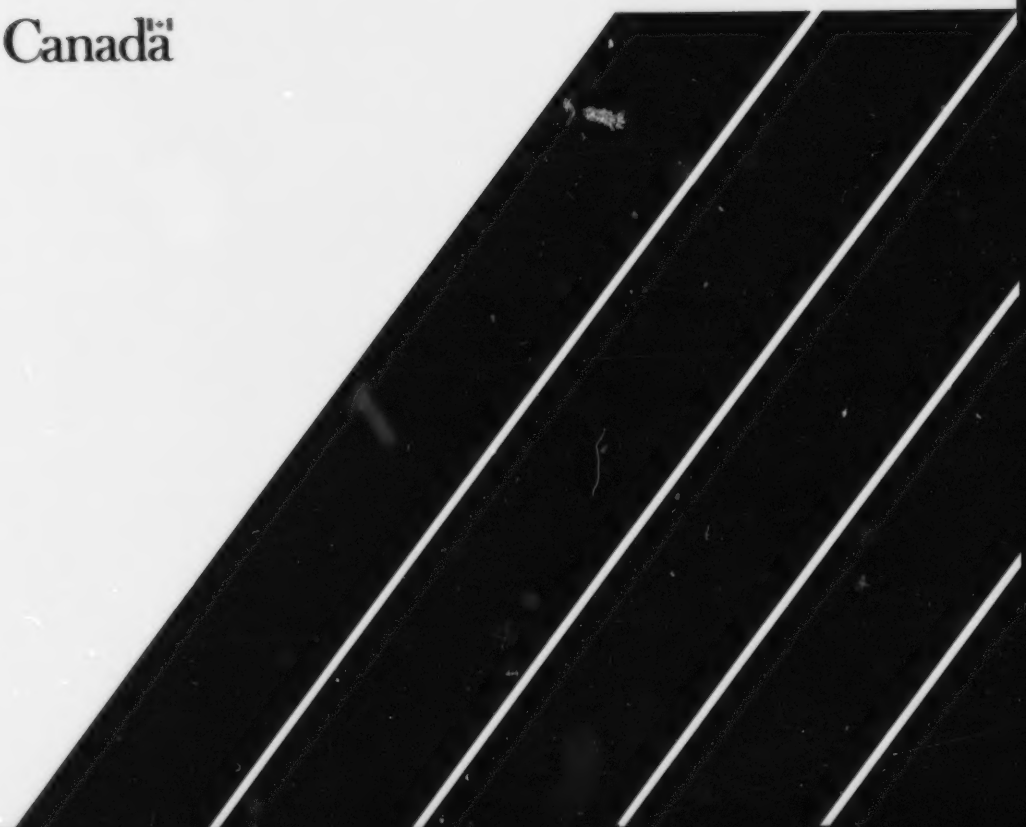
Centre canadien de la
technologie des
minéraux et de l'énergie

**Mining
Research
Laboratories**

**Laboratoires
de recherche
minière**



Canada



**RESULTS OF ULTRASONIC VELOCITY TESTING
ON I.D. SYSTEMS SAMPLES**

R. Jackson

MRL 89-57 (TR)

May 1989

20pp

MICROMEDIA

Introduction

I.D. Systems Inc. (IDS) approached the Canadian Mine Technology Laboratory on April 4, 1989 to conduct ultrasonic velocity tests on specimens which they would supply. Sample preparation and testing commenced on April 17, 1989 upon the receipt of five grab samples from IDS and was completed April 19, 1989. It is the purpose of this report to outline the procedures and summarize the results of that investigation.

Sample Preparation

As mentioned, five irregular shaped specimens were received from IDS. Petrographic analyses of the samples were not available and none were conducted. One cylindrical specimen was cored from each sample using a water-cooled, diamond impregnated core drill. The rocks were oriented to maximize specimen length without regard to rock structure or fabric. Uneven surfaces were then removed by means of a water-cooled diamond saw and rough ground with a water-cooled surface grinder. Samples were ground to their final dimensions and tolerances (length variation = $\pm 0.001 \times$ specimen diameter, perpendicularity = $\pm 0.25^\circ$, flatness = ± 0.025 mm) using CANMET's double lapper.

Description of Test Measurements and Procedures

The testing equipment consisted of transmitting and receiving platens containing piezoelectric transducers, a high voltage pulse generator and a Tektronix 468 digital storage oscilloscope equipped with delay sweep and a time base resolution of 0.01 microseconds. Zero delay corrections were calculated by extrapolation from arrival times determined for three steel reference specimens of different lengths.

The samples, numbered 1 to 5, were oven-dried under vacuum at 40°C for 12 hours and stored in a dessicator prior to actual testing. They were then placed between the platen heads using water as a couplant. Compressive waves were subsequently introduced by the excited piezoelectric cell at one end of the sample and arrival times measured with the oscilloscope at the other. Specimens were then evacuated and saturated in distilled water for another 12 hour period after which velocity testing was repeated. A copy of the instruction manual for the velocity equipment is appended to this report in the event a more detailed description of the procedure is required.

Longitudinal (compressive) wave velocities were determined according to the expression:

$$V_p = \frac{L}{t_p - t_0} \quad (1)$$

where; L = specimen length

t_p = transit time

t_0 = zero delay correction

Observations

Final individual specimen dimensions and test results are summarized in Table 1.

Table 1: P-Wave Velocity Test Results					
Sample No.	Length (mm)	Diameter (mm)	Density (gm/cc)	Longitudinal Velocity (km/s)	
				Dry	Saturated
1	91.04	44.72	2.71	5.86	6.31
2	77.00	44.68	2.77	6.11	6.14
3	64.00	44.68	2.74	5.32	6.28
4	63.14	44.68	2.61	5.62	5.93
5	100.30	44.70	2.67	6.20	6.35

Mean values of 5.82 km/sec ($\sigma = 0.36$) and 6.20 km/sec ($\sigma = 0.17$) were calculated for the dry and saturated samples, respectively and represent relatively high velocity rock types.

TABLE OF CONTENTS

	Page
1.0 - INTRODUCTION	1
1.1 - Sonic Pulse Generator	1
1.2 - Pulsing and Sensing Heads	2
1.3 - Oscilloscope	3
1.4 - Hook-Up	3
2.0 - TEST METHODS	4
2.1 - Test Specimens	4
2.2 - Measurement of Travel Distances and Density	5
2.3 - Attaching the Pulse Heads to the Specimen	5
2.4 - Determining the Pulse Travel Times	6
2.5 - Compression (p) Waves	6
2.6 - Shear (s) Waves	6
2.7 - Calibration Procedures	7
3.0 - CALCULATION OF ELASTIC CONSTANTS	9

INSTRUCTION MANUAL

SONIC VELOCITY EQUIPMENT

1.0 - INTRODUCTION

The complete sonic velocity equipment consists of 1), a pulse generator with oscilloscope trigger 2), pulsing and sensing heads containing piezo electric crystals 3), connecting cables for connection to an oscilloscope and 4), accessories which may include a phenyl salicylate dispensing kit and calibration cylinders for periodic checking of the time constants of the heads. An oscilloscope is most convenient for displaying the pulses and measuring the travel time.

1.1 - Sonic Pulse Generator: The pulse generator is designed to put out a voltage pulse with a maximum amplitude of around 800 volts. The pulse is in the form of a rapid rise time with exponential decay. Because of the high energy output, the mechanical pulse produced by the pulsing head is easily picked up by the sensing head where it is transformed into an electrical signal which can be displayed on the scope without the need for any pre-amplification.

Because the voltage output is high, care must be taken to avoid electric shocks, and in no circumstances should the pulse generator be connected directly to the scope.
 PULSE GENERATOR OUTPUT BE CONNECTED

The circuit diagram of the sonic velocity pulser is shown in Fig. 1.

The repetition rate of the output pulses is controllable and can be set using the center knob at between 30 and 120 pulses per second. Generally the best pulse rate is around 60 pulses per second which produces a steady trace on the oscilloscope and is free from "ringing." "Ringling" may occur at high pulse repetition rates and is caused by the previous pulse not having sufficient time to completely

die away before the next pulse occurs. "Ringing" causes unsteady traces on the scope.

Note that there is a slight dependence between pulse repetition rate and pulse travel times. As the pulse repetition rate increases, the travel times are slightly longer. It is advisable wherever possible to use the same repetition rate for all tests.

The repetition rate can also be adjusted by a secondary control located on the back of the instrument. This control enables the repetition rate to be set to some convenient number when the front control knob is indexed to a certain scale division.

The circuit is protected by a 1/2 amp slow-blow fuse on the 115 v. 50 cycle input line.

Coaxial cable connectors are type MHV (Amphenol UG931/U and UG932/U).

1.2 - Pulsing and Sensing Heads: The pulsing and sensing heads are identical in every respect and are interchangeable. Pulsing and sensing heads are sold in pairs; one type is designed to generate and sense p waves; another type is designed to generate and sense s waves.

The design of the heads is shown in Fig. 2. This type of head is designed specifically for testing NX size diamond drill cores. There is no restriction on the upper size limit of drill core that can be tested, and a rock core of as little as 3/4 in. diameter could be tested. All that is required are two flat parallel surfaces.

If the rock sample (or other material) is to be tested at various stress levels, then the standard heads can only be used with NX cores. For other core sizes, tests at different stress levels will require heads which are the same diameter as the core.

Note that the piezo electric crystals are bonded in place inside the heads using an electrically conductive epoxy adhesive. Occasionally the bond may fail resulting in a marked change in the characteristic of the pulse wave form. If

this should happen, then the crystal should be rebonded in position. The crystal is held against the bottom of the head by means of pressure exerted by the allen screw in the center of the top of the head. Greater coupling and sensitivity is achieved by tightening this allen screw. The allen screw should not be over-tightened, because this would cause the lower face of the head to bulge outwards. Also excessive pressure will break the crystal. The lower face is quite thin and should be perfectly flat. Flatness is not so essential with p wave heads but is important where s waves are being generated.

Resonant frequencies of the crystals are 600 KHZ for the p wave heads and 800 KHZ for the shear wave heads.

1.3 - Oscilloscope: The oscilloscope requirements are not unusual. The time base should be able to operate at speeds as fast as 10 μ sec/cm and the vertical scale amplitude should be as little as 0.02 volts/cm.

Single beam oscilloscopes can be used with external triggering; also dual beam oscilloscopes can be used to display both trigger pulse and output pulse. Times can be measured using delayed sweep controls on the oscilloscope or by measuring distances using a scale. If the latter method is used, a polaroid camera attachment enables the measurements to be made conveniently.

1.4 - Hook-Up: A typical hook-up using a storage type oscilloscope (similar to a Tektronix Model 564) is shown in Fig. 1a. Connect pulsing head to generator connector marked 1000V. Connect generator connector marked trigger to channel 1 of oscilloscope. Connect sensing head to channel 2 of oscilloscope.

2.0 - TEST METHODS

The sonic velocity apparatus can be used to measure the free medium velocities of compression waves and shear waves. The two velocities may be used to calculate the dynamic elastic constants (Young's Modulus, Poisson's Ratio). These constants are not necessarily the same as the static elastic constants nor need they be the same as 1), dynamic constants measured by other methods 2), seismic velocities, although they should be good approximations.

The dynamic testing method described below offers a very simple and rapid means of measuring elastic constants and the effect on these constants of increasing stress and differing water contents. These parameters are in turn useful in engineering design.

2.1 - Test Specimens: Test specimens require two flat parallel surfaces between which the travel times of the p and s waves will be measured. The faces should be flat ± 0.001 in. and parallel ± 0.005 in. per inch separation.

Since the moisture content can affect the pulse velocities, care should be taken to preserve the original moisture content if the existing underground conditions are to be duplicated. Alternatively the samples can be tested in an as received condition, and also in a dry and completely saturated condition to obtain a full range of pulse velocity variations with moisture content.

The ratio between the pulse travel distance between parallel faces and the minimum lateral dimension should not exceed five if reliable free medium velocities are required.

Similarly the minimum lateral dimension of the test specimen should be at least ten times the wavelength of the compression wave. Also the wavelength should be at least twice the average grain size of the material. Fig. 4 shows graphically some of the size limitations. For any particular value of V_p/f the permissible values of specimen diameter lie above the diagonal line while

permissible values of grain size lie below the diagonal line.

2.2 - Measurement of Travel Distances and Density: Travel distances between the flat parallel surfaces should be measured to within 0.1%. The weight and volume should be measured, the weight in grams and the volume in cc's. For regular drill cores, the volume should be calculated from external measurements to within 0.1%. For irregular specimen shapes, Archimedes' principle can be adopted provided that the immersion of the sample in the fluid can be tolerated.

When the weight and volume of the sample have been measured, then the specific gravity should be calculated in grams per cubic centimeter.

Note that the moisture content in the as received condition may be measured by subsequently drying the sample and measuring the loss of weight. Similarly the porosity can be measured by completely saturating the sample when the difference between the weight of the dry and the saturated sample is the weight of water held in the pore spaces, which is equal to the volume of the pore spaces in cc's. This volume compared with the total volume will give the porosity. The degree of saturation in the as received condition or in the original in situ condition can be obtained by comparing the moisture content in these conditions with the maximum possible moisture content at complete saturation.

2.3 - Attaching the Pulse Heads to the Specimen: This is accomplished by using phenyl salicylate which is kept molten using a hot plate at 80° C. (approximately), and is dispensed from the dish on the hot plate by means of an eye dropper. A small bead of molten phenyl salicylate is squeezed onto the horizontal surface of the head or rock sample and the rock or head is squeezed down over the bead while still molten. When the material solidifies in a few seconds, a good mechanical bond is obtained such that it is not necessary to put the assembly in a clamp to hold it firmly together. After the test, the bond is broken by a smart sideways blow, or in the case of a weak rock by prying apart using a sharpened screwdriver.

2.4 - Determining the Pulse Travel Times: The oscilloscope can be used with the delayed sweep provision or with an external time delay circuit to display the wave form of the transmitted pulse.

2.5 - Compression (p) Waves: The first arrival time of the compression wave is very easily determined since it is marked by the first deviation of the wave form from the initial horizontal straight line. Generally, the polarity of the wave form is such that the wave will first deviate in a downward direction. The vertical amplitude of the scope should be adjusted to a maximum in order to create as sharp a "knee" as possible to measure to. The travel time measurement is then made simply from the start of the trace to this "knee." Actually, a minute portion of the travel time is not recorded--perhaps about 1 μ second due to the fact that the scope triggers about 1 μ second after the pulse is initiated. However, there is no problem since this small time is accounted for when the time delay involved in the waves passing through the pulsing heads is corrected for.

2.6 - Shear (s) Waves: First arrival times of shear waves are not so readily discernable because the shear plate type of piezo electric crystal will invariably generate some compression wave components which will arrive ahead of the shear waves. The compression wave so generated will cause an initial downward deviation of the wave trace in the same manner as previously described. In fact, the shear wave heads can be used to measure the travel times of both p and s waves, except that the initial "knee" of the compression wave arrival is not so clearly defined on the shear wave pulse heads as on the compression wave pulse heads. Hence the measurement of the p wave travel time cannot be so precisely measured.

Some time after the p wave has arrived at the sensing head, the s wave arrives and causes a large upward sweep of the oscilloscope trace. Two examples of this are shown in Fig. 3.

Note that the shape of the wave traces in these two figures are different because

of the different rock types involved.

Because the shear wave arrival occurs after the p wave arrival, it is impracticable to use electronic timers to measure s wave arrival. The travel time of the s wave is obtained simply by measuring from the start of the trace to the start of the strong upward sweep which usually occurs at the bottom of a valley.

There are variations of wave form caused by different material properties, particularly laminations, bedding planes, foliation, pore spaces, and vugs. These variations should be investigated by the operator since they are too difficult to describe here. Also the operator should familiarize himself with the effect of different travel distances between the two test surfaces. This can be done by using different sized samples of the same material, which is also a good means of measuring the travel time of the pulses through the heads (see later).

Other wave shape variations are caused by relative orientation of one head with another. This is particularly so with the shear wave pulse which generates transverse vibrations oriented in one particular direction. Naturally the sensing head crystal should be oriented so that the vibration direction of the incoming shear waves coincide with the vibration axis of the crystal in order that the mechanical pulses be converted to electrical signals without undue loss of efficiency. Again it is wise for the operator to experiment with various orientations to understand more fully the phenomena observable.

2.7 - Calibration Procedures: As with all oscilloscope measurements, a periodic check of the time base accuracy is advisable. This can be done by impressing a known frequency onto the oscilloscope.

The travel time of the pulses through the heads themselves must be measured and subtracted from observed travel times in order to obtain the travel times of the pulses through specimen only.

The zero correction can be obtained in two ways. The heads can be bonded directly together and measurements made. This method is acceptable, but due to

the close juxtaposition of the crystals, the results are influenced quite markedly by slight relative offsets or misorientations. Another more refined method is to measure the travel times in several specimens of the same material having different travel distances. The results when plotted as in Fig. 5, i.e., travel time versus travel distance, will yield a straight line which can be extrapolated back to zero travel distance to give the time of travel in the heads only.

This system is also useful if the material used has known elastic properties when the actual travel times can be compared with those theoretically obtained from these known properties. This serves as a check on the system.

3.0 - CALCULATION OF ELASTIC CONSTANTS

The calculation of elastic constants assumes that the material under investigation is isotropic. If the material is anisotropic, then the assumptions do not hold, and although elastic constants may still be calculated, they will be in error.

The recommended system of calculation is as follows:

1. Determine the "dynamic" density by multiplying the specific gravity in grams/cc by the factor 9.35×10^{-5} . This yields ρ in units of sec^2/in^4 .
2. Determine the shear wave velocity V_s and the compression wave velocity V_p after suitably correcting for travel times in the heads themselves. Now calculate V_s^2 and V_p^2 . All units should be retained in inches and seconds.

3. The shear modulus G is given by the simple equation

$$G = \rho V_s^2 \text{ psi}$$

$$\text{where } G = E/2(1+\mu)$$

$$E = \text{Young's Modulus psi}$$

$$\mu = \text{Poisson's Ratio}$$

4. Poisson's Ratio is given by the equation

$$\mu = \frac{(V_p^2 - 2V_s^2)}{2(V_p^2 - V_s^2)}$$

5. After calculating μ then Young's Modulus is simply obtained from the formula

$$E = 2G(1+\mu) \text{ psi}$$

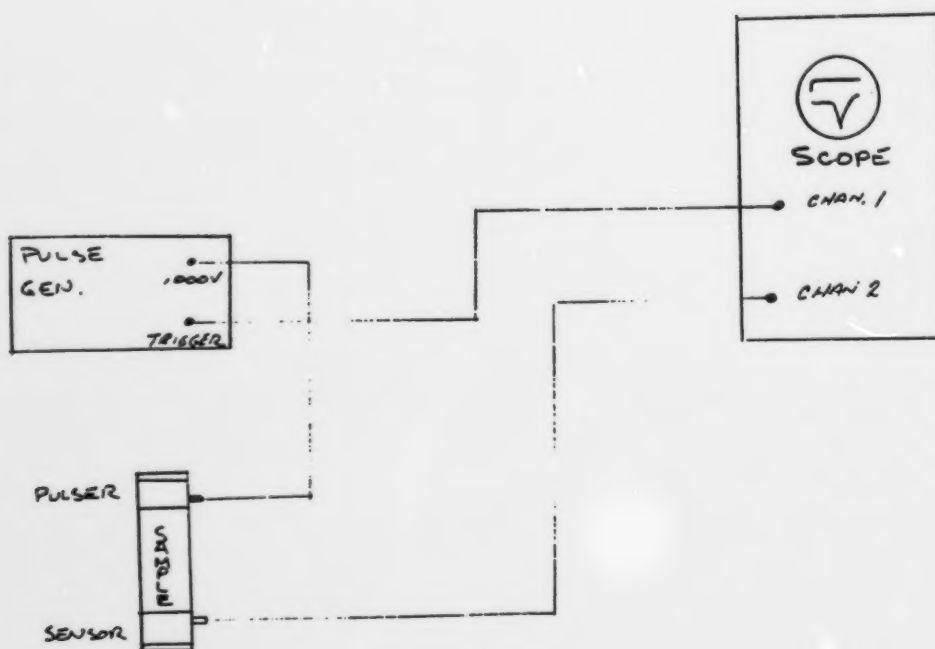


FIG. 1a - TYPICAL HOOKUP

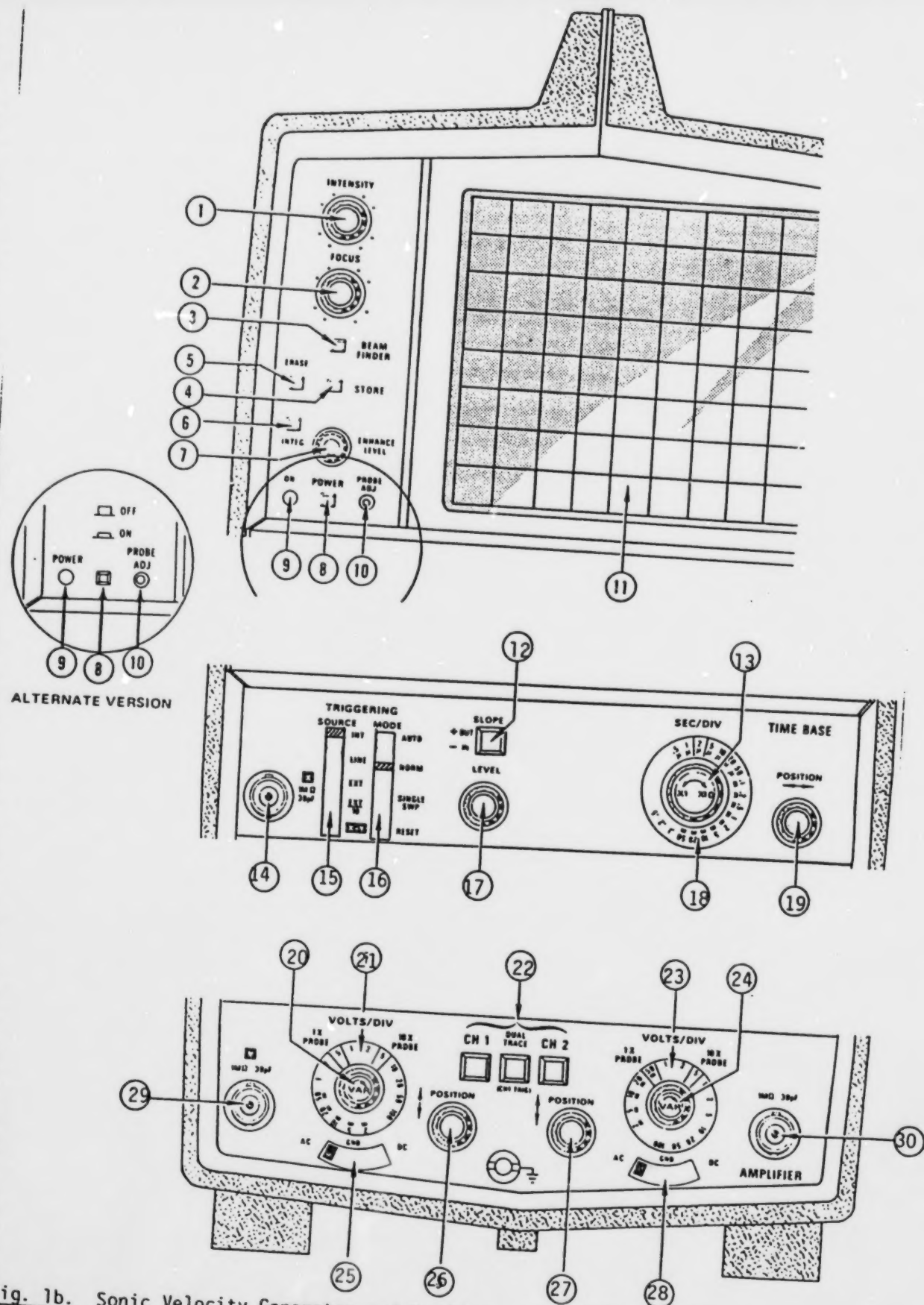


Fig. 1b. Sonic Velocity Generator and Head Hook-up to TEKTRONIX T912, Storage Oscilloscope.

Notes Corresponding to Fig. 1b.

Call out
No.

1. thru 11.

See Tektronix instruction manual.

Not used - leave out

12.

X1-X10 - use X1, fully CCW.

13.

Not used.

14.

Triggering Source - use INT

15.

Triggering Mode - use NORM

16.

See Tektronix* manual. * (VERY SENSITIVE)

17.

Sec/Div. use 5 to 20 μ .

18.

See Tektronix manual.

19. -

VAR: All the way clockwise

20. -

Volts/Div. normally 5 on 1X probe or other preference.

21.

CH1-out, CH2-out, dual trace-in.

22.

Volts/Div. normally 50M on 1X probe.

23.

VAR: All the way clockwise

24.

Use AC

25. & 28.

See Tektronix Manual

26.

See Tektronix Manual

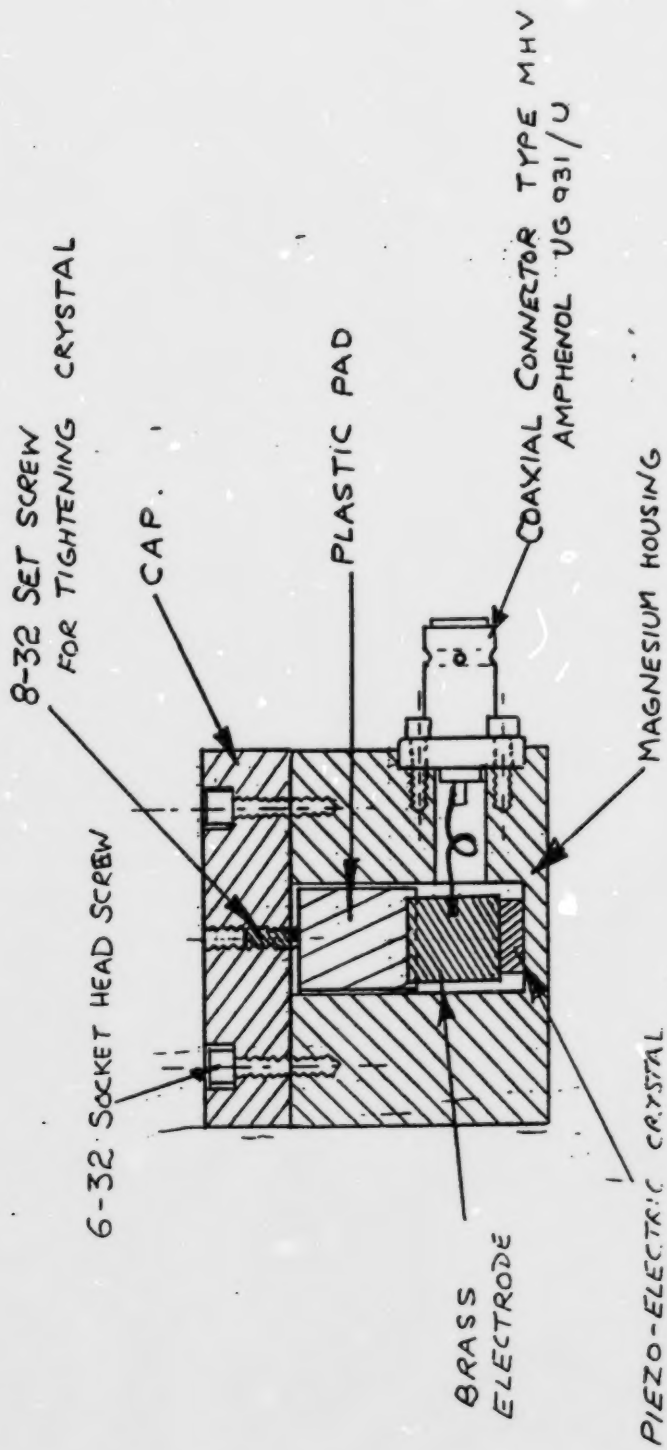
27.

From pulse generator TRIGGER (CH.1)

29.

From receiving transducer head (CH.2)

30



TERRAMETRICS, INC.

16027 WEST 5TH AVE.

GOLDEN, COLORADO 80401 USA

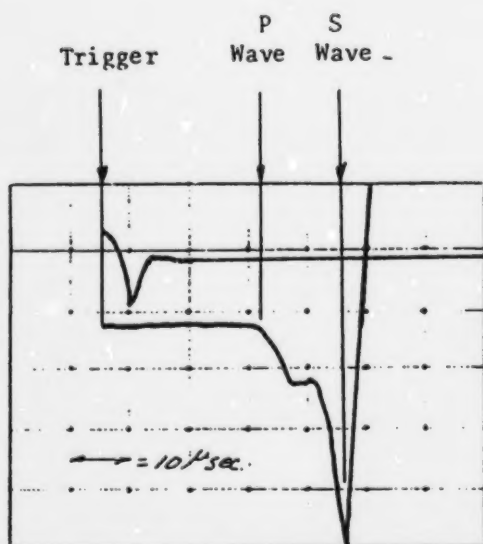
SCALE NONE DRAWN BY L. W. B. S.

DATE APR 72

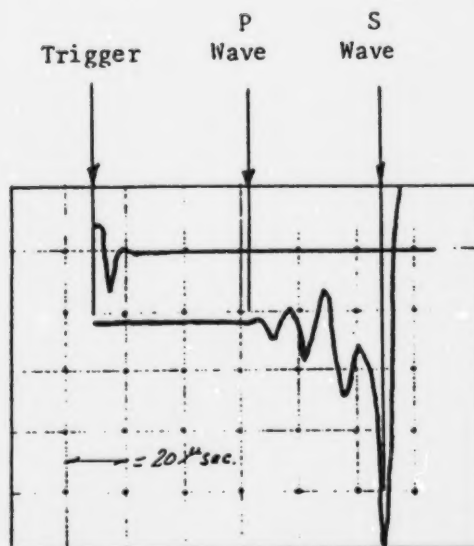
SONIC PULSE HEADS

APPROVED BY

DRAWING NO. FIGURE 2



Granite
 $E = 10 \times 10^6 \text{ psi}$



Oil Shale
 $E = 1 \times 10^6 \text{ psi}$

Fig. 3. - Typical Oscilloscope Traces

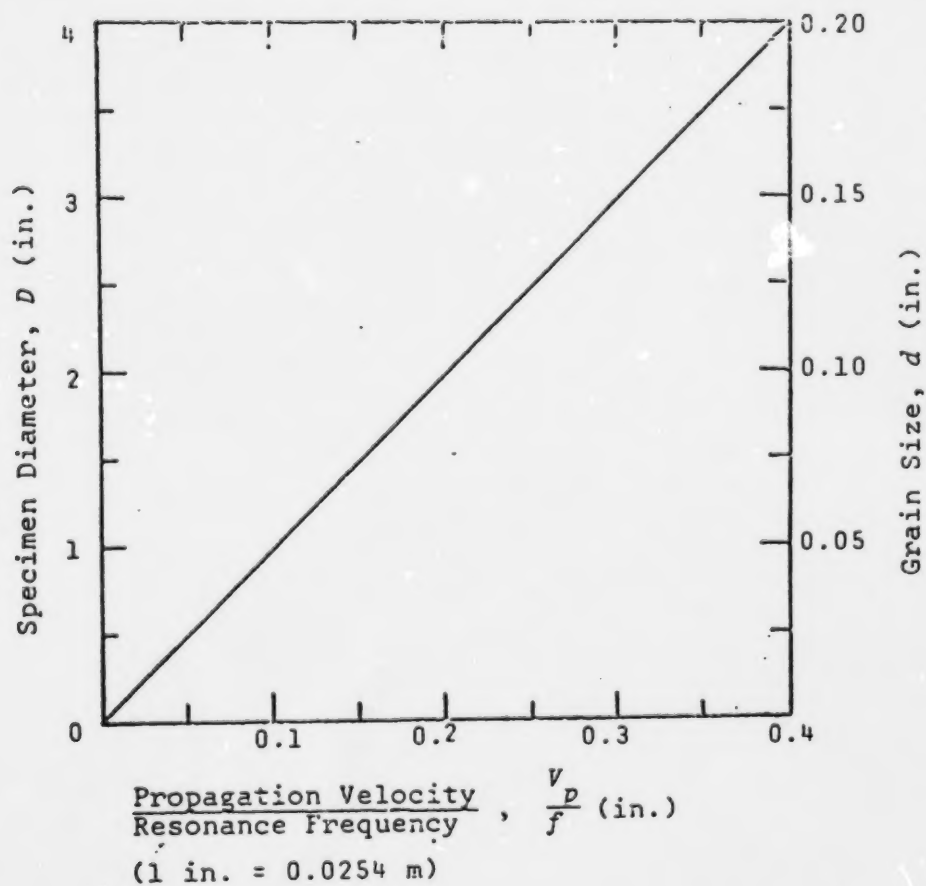


Fig. 4 - Graph Showing Allowable Values of Specimen Diameter and Grain Size Versus the Ratio of Propagation Velocity to Resonance Frequency.

CALIBRATION CHART

For _____

1

40

30

20

10

0

TRAVEL TIME - μ Sec.

1

2

3

4

5

TRAVEL DISTANCE - Inches

50 Hz WAVE

SPECIMENS



TERRAMETRICS INC.
16027 WEST 5th AVE.
GOLDEN, COLORADO 80401 USA

SCALE _____ DRAWN BY _____ DATE _____

SONIC PULSE GENERATOR
SER. NO. _____

APPROVED BY _____

DRAWING NO. FIG. 5